Improving irrigated wheat grain yield and soil quality through diverse summer green manure cover cropping systems

Mohammad Reza Mehrvar

Email: mehrvarmr@outlook.com

Abstract

This study evaluates integration of irrigated wheat production with a short summer weedy fallow, summer green manure cover crops, volunteer wheat, low-energy shallow incorporation (light disc harrow), and double minimum tillage to improve wheat productivity, quality, and soil organic carbon (SOC) while drastically reducing summer use of synthetic fertilizers and herbicides. Sixteen summer green manure/cover crop (SGMCC) treatments were compared in a randomized complete block design across two consecutive years. Although grain-yield responses were small and variable among cover-crop species, legume SGMCCs such as hairy vetch, mung bean and cowpea produced clear soil fertility and SOC gains and produced positive legacy effects in year-to-year productivity. The shallow, low-speed disc incorporation preserved much of the surface residue structure, contributing to increases in measurable SOC and favorable soil structural changes over the study period. These findings align with recent global meta-analyses showing modest mean increases in main-crop yields from cover cropping but consistent SOC and aggregation benefits when cover crops are combined with reduced/residue-retaining tillage systems. Adoption of short summer SGMCCs followed by light, shallow incorporation under a double minimum tillage framework can enhance resilience and soil health in irrigated wheat systems, although outcomes remain context-dependent (soil, climate, species selection).

Keywords: wheat, cover cropping system, green manure cover crops, grain yield, soil organic matter

*This study was conducted as part of the PhD thesis of the first author at Urmia University, Urmia, Iran. The study was a collaborative effort between the first and second authors, who are PhD students, and their supervisor (second corresponding author). It is a result of a four-year research project, approved under project number 960503-055-03-03-2 by the Agricultural Research, Education, and Extension Organization (AREEO) of the ministry of agriculture Tehran, Iran. The research project was carried out by the supervisor from 2017 to 2021 at the experimental fields of the cereals research department in the Seed and Plant Improvement Institute (SPII) located in Karaj, Iran.

Introduction

The challenges facing modern agriculture are multifaceted and urgent. Escalating global populations demand increased food production, while environmental concerns such as soil degradation, water scarcity, and climate change necessitate sustainable agricultural practices. In other words, soil degradation and declining crop yields or stagnation have become significant challenges in modern irrigated cropping systems. Agricultural sustainability hinges on maintaining soil health while ensuring optimal crop yields. Conventional practices have often led to soil degradation due to reduced organic matter, soil compaction, and nutrient depletion. Green manure cover cropping systems offer an ecologically friendly solution by introducing a variety of crop species to improve soil fertility and structure. In response, sustainable crop management practices that enhance soil fertility and crop productivity are essential. Green manure involves planting specific cover crop species during fallow periods or between main crops, with the intention of incorporating the plant biomass into the soil to improve its structure, fertility, and nutrient content. The practice capitalizes on the ability of certain green manure cover crop species to harness their with various ecosystem services and benefits to irrigated wheat. The essence of green manure lies in its ability to merge ecological principles with agronomic strategies. By selecting specific cover crop species and tailoring their incorporation into the cropping cycle, farmers can enhance soil fertility, improve water retention, suppress pests and diseases, and reduce the need for synthetic fertilizers. These cover crops, often referred to as "living mulches," enrich the soil during fallow periods, protect it from erosion, and stimulate essential soil microorganisms.

Wheat, accounting for over 20% of the world's energy consumption and 25% of its protein intake, ranks among the most important cereal crops (Reddy and Hodges, 2000). Wheat as a strategic crop possesses adaptability to various climatic conditions and is cultivated worldwide (*Hasheminasab et al.*). Presently, wheat occupies about 16% of global arable land, with approximately 221 million hectares under cultivation in 2021 (FAO). Intensive and unsustainable agriculture contributes to land degradation and environmental issues such as pollution, soil erosion, declining fertility, reduced biodiversity, and increased greenhouse gas emissions. Sustainable agricultural practices like green manure cover cropping and crop residue retention have been introduced as cost-effective solutions capable of ameliorating land degradation, enhancing food security, and ensuring climate resilience (*Francaviglia et al.*, 2023).

Currently, two-thirds of the world's soils contain less than 2% organic carbon. Increasing soil organic carbon and reducing reliance on nitrogen fertilizers are essential to address global yield gaps (Oldfield *et al.*, 2019). One key pathway to carbon sequestration in soil is boosting carbon input. Embracing cover crops within cropping systems is recommended as a management strategy to enhance soil organic carbon reserves (*Mazzoncini et al.*, 2011). The benefits of cover crops encompass various aspects, including soil physics advantages such as soil erosion prevention, soil aggregate stability, hydraulic soil properties, soil density, weight, and temperature improvement. They also encompass chemical benefits like soil carbon and organic matter, soil nitrogen, primary and micronutrients, as well as biological advantages such as soil microbial population and activity, earthworm populations, and pest management (*Adetunji et al.*, 202.).

The impacts of cover crops can be influenced by a range of regional factors, encompassing aspects such as climate and farm management practices. Soil properties, cover crop type (legumes or non-legumes), cover crop season (winter or summer), and nitrogen input are factors that impact the primary crop yield (Fan, *et al.*, 2021). Therefore, by planting cover crops, besides supplying companion crop nitrogen, the pressure from weeds also decreases (Hooker *et al.*, 2008). In fact, considering the role of

cover crops in suppressing weeds in agricultural fields, their utilization in agriculture is increasing nowadays (Didon *et al.*, 2014).

Cover crops have positive effects on crop production, leading to an increase in crop yield of up to 24% in organic reduced tillage systems, whereas in conventional tillage systems, this increase is only around 2% (Wittwer *et al.*, 2017). Summer cover crops, especially those planted before wheat cultivation, can enhance wheat yield by altering the soil microbial population structure towards optimal soil conditions (Sen Li *et al.*, 2017). Another study has reported that rye, belonging to the grass family, and also the legume cover crops can improve soil structure and modify soil microbial communities (Wu *et al.*, 2006; Guo *et al.*, 2008; Poffenbarger *et al.*, 2015). McDaniel *et al.* (2014) indicated that cover crops help maintain soil quality and fertility by increasing soil carbon, nitrogen, and microbial biomass, contributing to agricultural ecosystem sustainability. Additionally, Rose *et al.* (2012) suggested that winter cover crops can enhance soil structure and aggregate formation due to root mechanical effects and secretion of adhesive substances. Considering the research findings, it can be concluded that the appropriate use of summer green manure cover crops in sequence with wheat can significantly improve wheat yield and soil properties. The main objective of this study was to identify and introduce suitable green manure cover crops for the spring wheat sequential cropping system in Alborz province. Furthermore, one of the secondary objectives of this research was to investigate the effects of summer cover crop-wheat cropping sequences on wheat yield and certain biological, physical and chemical soil properties.

Materials and Methods

The research findings of this paper obtained from 3rd and 4th years of the 4 years research experiment conducted in the experimental fields of department of cereals research of seed and crop improvement institute affiliated with the agricultural research, education, and extension organization (AREEO). The field is located at geographical coordinates (39°S, X=492886, Y=3960330) and an elevation of 1321 masl. The mean minimum temperature in this region varies between 7°C and 15°C with the mean annual temperature of 14 degrees Celsius, and the number of frost days ranges from 50 days. The annual total precipitation mean at Karaj in the Alborz province was 265mm for years 1951-2010, mean annual precipitation of 251.7 mm in years 1985-2010 but decreased to 70.8 mm in years 1985-2015. The monthly mean climatic data for the years 1985-2015 is shown in Figure 1. The year 2022 was a record in 50 years as the driest years for Iran with the lowest precipitation in Fall and Winter, except Spring with a lot of rainfall. This shows that even in the irrigated wheat production environments we need to mitigate drought impacts through proper soil managements such as green manure cover crop-based wheat production systems to help the soil with more organic carbon storage with more water holding capacity and other improved soil properties as providers of ecosystem services to wheat as the main crop.

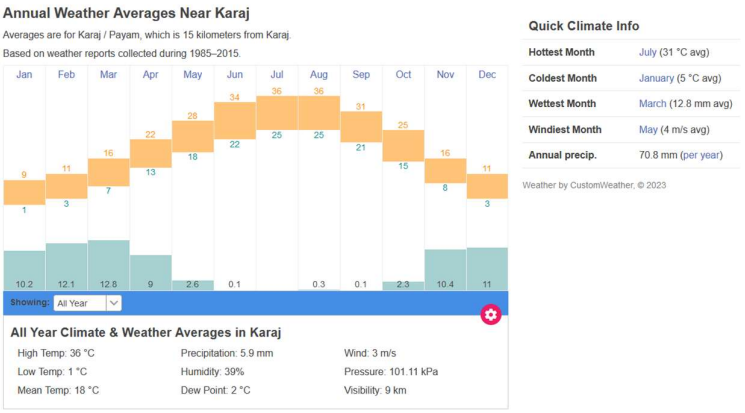
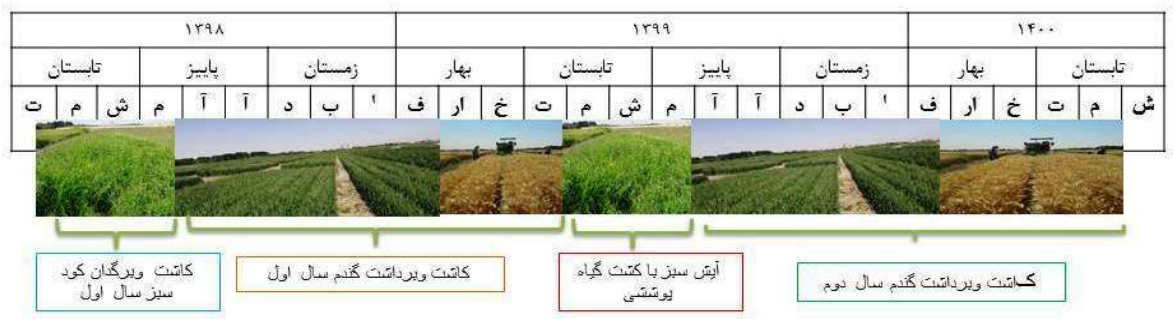

Annual Weather Averages Near Karaj
Averages are for Karaj / Payam, which is 15 kilometers from Karaj.
Based on weather reports collected during 1985–2015.
Jan Feb Mar Apr May Jun Jul Aug Sep Oct Nov Dec
9 11 16 22 28 34 36 36 31 25 16 11
1 3 7 13 18 22 25 25 21 15 8 3
10.2 12.1 12.8 9 2.6 0.1 0.3 0.1 2.3 10.4 11
Showing: All Year
All Year Climate & Weather Averages in Karaj
High Temp: 36 °C
Low Temp: 1 °C
Mean Temp: 18 °C
Precipitation: 5.9 mm
Humidity: 39%
Dew Point: 2 °C
Wind: 3 m/s
Pressure: 101.11 kPa
Visibility: 9 km
Quick Climate Info
Hottest Month July (31 °C avg)
Coldest Month January (5 °C avg)
Wettest Month March (12.8 mm avg)
Windiest Month May (4 m/s avg)
Annual precip. 70.8 mm (per year)
Weather by CustomWeather, © 2023

Figure 1: Monthly mean climatic data for Karaj (1985-2015)

The experiment was conducted using RCBD in three replicates with 16 treatments. The experimental plots were 11.5 and 4.8 meters in length and width, respectively. The experimental years of study of study were 2019 and 2020 on spring bread wheat cv. Baharan in seeding rate of 400 seeds per square meter in each year. GMCCs were cultivated in midsummer with a growth period of 60 to 65 days until mid-October as the termination date for soil incorporation of all GMMCCs with light disc harrow three weeks before sowing next wheat seeds in the 1st week of November. Irrigation was carried out based on the water requirements of the crops using the furrow irrigation method.

Figure 2: Schematic crop calendar for the implementation of the experiment in two agricultural years



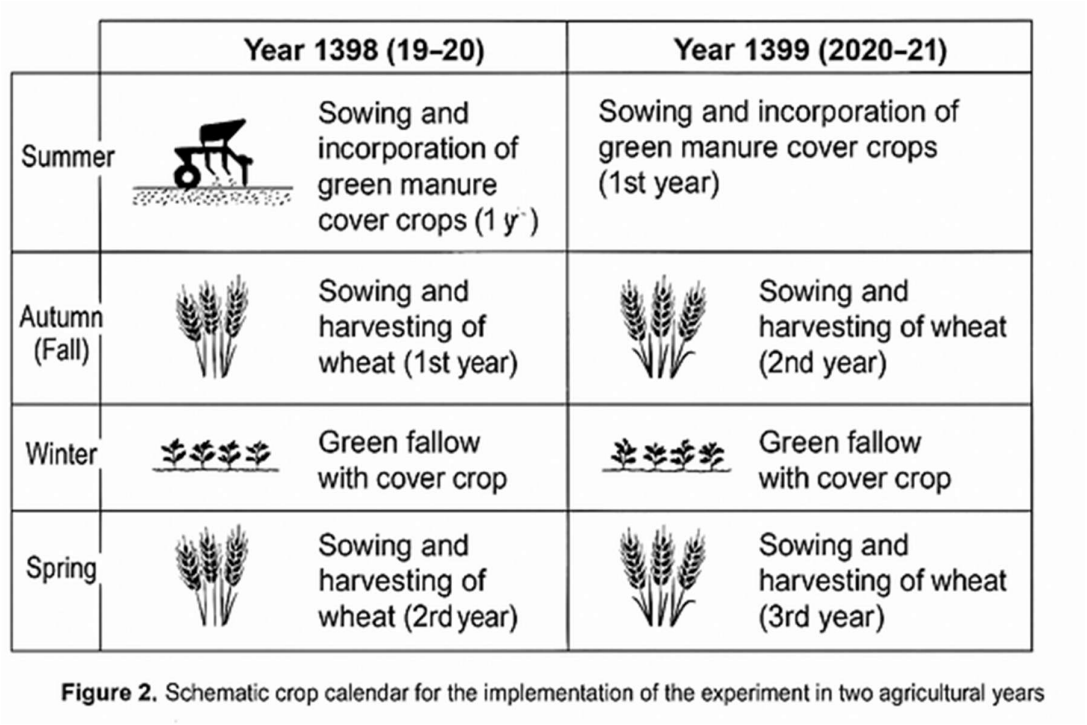

Year 1398 (19–20)
Year 1399 (2020–21)
Summer
Sowing and incorporation of green manure cover crops (1 y-1)
Sowing and incorporation of green manure cover crops (1st year)
Autumn (Fall)
Sowing and harvesting of wheat (1st year)
Sowing and harvesting of wheat (2nd year)
Winter
Green fallow with cover crop
Green fallow with cover crop
Spring
Sowing and harvesting of wheat (2rd year)
Sowing and harvesting of wheat (3rd year)

Figure 2. Schematic crop calendar for the implementation of the experiment in two agricultural years

Prior to wheat sowing, composite soil samples were collected from the field. Three samples were prepared and transferred to the soil and water research institute laboratory for the measurement of soil physical and chemical properties. The mean results are presented in Table 1.

Table 1: Soil test results of the experiment before implementing the research project

Cation Exchange Capacity (CEC)	Clay %	Silt %	Sand %	Electrical Conductivity (EC)	pH	Nitrogen %	Phosphorus %	Potassium %	Organic Carbon %	Soil Organic matter %
16.34	24.33	38.67	37	1.27	7.98	0.04	7.4	148.33	0.45	0.77

In this study, green cover crops were used in 16 different treatments, including grain sorghum, forage millet, sorghum-sudan grass, barley, berseem clover, crimson clover, cowpea, canola, mung bean, rye, hairy vetch, oat, safflower, soybean, sesame and sainfoin. These green manure cover crops were sown in midsummer after a short summer weedy fallow with the duration of about 45 days after wheat harvest. Once the cover crops reached the flowering stage in about 65 days after seed sowing, it was soil incorporated using a light disc harrow John Deere™ model 301, maintaining a forward speed of 10 to 12 km hour^{-1} and working at a depth of less than 15 Cm, in order to be in adaption with conservation tillage conditions. Prior to harvesting the cover crops, crop samples were collected and transferred to the laboratory for determination of fresh and dry biomass weight. For wheat cultivation in the two agricultural years 1398 and 1399, the variety used was "Baharan" spring wheat. The seeds of this variety were sown with a seeding density of 400 seeds per square meter, based on its thousand grain weight, 20 days after incorporating green manure cover crops in fixed experimental plots in consecutive years of study. Seed drilling method was with experimental plot seeder Wintersteiger™ employed for sowing the small-grain cereal on plots managed as 15-30% past year wheat residues kept on the soil surface and 70-85% soil incorporated. For assessing the yield performance, one year of the wheat crop's life cycle, from cropping to harvest, is considered as a reference and compared with the

same period of the following year to express yield performance changes. However, for the cover crop, the growing period after wheat harvest is approximately 45 days, and the period of green manure cover crop cropping in the two treatment sets is around 60 to 65 days. Sampling for assessing the residual cover crop biomass was done prior to wheat cropping in the fall. After sowing the wheat seeds, preparations were made for irrigation lines corresponding to each of the plots to ensure uniform irrigation across the field. Subsequent irrigations were performed using furrow irrigation method stacked with a subsurface irrigation system, based on the crop's water requirements. Basic fertilizers, including 150 kilograms of triple superphosphate, 100 kilograms of potassium sulfate, and 100 kilograms of urea, were applied simultaneously with cropping, based on soil test results. Additionally, in three stages, supplementary fertilizers were applied according to the crop's growth stage during the spring season. The wheat harvest took place in early July using a trial combine harvester, with two margin rows excluded. The purpose was to determine the yield of each plot. The harvested crop from each plot was weighed separately. Prior to harvesting from each plot, a sample comprising leaves, stems, and heads was collected, forming a floor area of 0.5 meters by 0.5 meters at a depth of 5 centimeters from the soil surface. This sample was taken to the laboratory to assess yield-related characteristics and components such as the number of grains per head, thousand grain weight, and the number of heads per unit area. These measurements were carried out to evaluate the yield performance of each plot. The results obtained from this study were analyzed using appropriate statistical tests, and the differences in means were examined using the Duncan's multiple range test for comparison.

Green manure cover crops characteristics

In this study, the effects of green manure cover crops were investigated by examining their characteristics. The results showed that based on the two-year mean, the traits of higher biomass, dry biomass (cover crop + weeds), net cover crop biomass, and weed biomass had statistically significant differences. However, the amount of dry matter did not show a significant difference. The effect of the year on the differences between treatments was not significant, indicating that the mean traits did not significantly differ between the first and second years, and the green manure cover crops did not exhibit significant differences in biomass production over two consecutive years.

Results and Discussion

In order to compare the yield performance of the two years of the study, the mean yield of the past ten years for wheat in Alborz Province has been utilized as a reference. The mean yield over the last ten years for wheat in Alborz Province has been 5068 kilograms (as shown in Table 2-1). The cultivated area under the "Baharan" spring wheat variety for the agricultural year 1400-1401 was 12,350 hectares, equivalent to 16% of the total cultivated area in Alborz province. This is illustrated in the graph (...). Furthermore, the cultivated area of this variety for the agricultural year 1401-1400 nationwide was 31,251 hectares, which corresponds to 1.64% of the total wheat cultivation area in the country.

Table2: Irrigated wheat grain yield means and production in some agricultural years and cultivated.

Row	Agricultural Year	Cultivated Area (hectares)	Production (tons)	Wheat Yield (kg/ha)
1	**2021-2022**	7725	43675	5654
2	**2020-2021**	9265	47974	5178
3	**2019-2020**	10117	55658	5501

Row	Agricultural Year	Cultivated Area (hectares)	Production (tons)	Wheat Yield (kg/ha)
4	**2018-2019**	10978	63675	5800
5	**2017-2018**	10243	44522	4347
6	**2016-2017**	10021	57079	5696
7	**2015-2016**	10437	55761	5343
8	**2014-2015**	10988	60013	5462
9	**2013-2014**	9366	35930	3836
10	**2012-2013**	6892	26606	3860
	Mean	9603.2	49089.3	5068

Source: Wheat Project Implementation Office, Ministry of Agriculture Jihad

Table 2 presents the two-year composite analysis of variance results related to green manure cover crop characteristics. According to the results obtained from Table 2, significant effects of the year, treatment, and the interaction effect between year and treatments were observed for certain traits.

Table 3 - Two-Year combined analysis of variance results for studied green manure cover crops

		Mean Square			
SOV	DF	Cover Crop Biomass-to-Total Biomass Ratio	Dry Biomass of Cover Crops	Dry Biomass of Weeds and Cover Crops	Fresh biomass
Year	1	15.84 ns	45937.5 ns	4241370.09 ns	3184273.5ns
Rep (Year)	4	388 ns	214671.9*	152414.8ns	2932169.9ns
GMCC	15	2617.26**	5854119.9**	270183.01*	9176370.7**
Year x GMCC	15	1771.22**	241341.9**	102079.98ns	*5833941.7
Error	60	290.322	79538.69	98779.572	268357.9
CV (%)		27.3	45.2	35.4	41.9

Note: "ns" indicates non-significant differences, and "/" indicates significant differences at the respective level. The coefficient of variation is presented as a percentage for each trait. *: Significant at the 5% probability level. **: Highly significant at the 1% probability level.

Table 3 demonstrates that the two-year mean characteristics of the studied green manure cover crops varied among the experimental treatments. Percentage of dry matter, cover crop biomass, dry biomass of weeds and cover crops, and the cover crop biomass to total biomass ratio showed significant differences among different two-year treatments. The highest cover crop biomass was attributed to Sudan grass, followed by clover and mung bean. In contrast, the lowest cover crop biomass was associated with oat and barley. Other traits such as dry matter percentage and green manure cover crop biomass also exhibited significant differences among the various two-year treatments.

Based on these results, selecting suitable green manure cover crops for soil improvement, fertility enhancement, and weed suppression can significantly impact the agricultural system's performance. Regarding dry biomass of green manure cover crops, no significant differences were observed between treatments across the two agricultural years. The effect of the year was not significant, and the highest dry biomass was linked to Sudan grass. Mung bean and clustered clover ranked next in terms of dry biomass production. Additionally, the lowest dry biomass was attributed to oat.

In comparison with other non-leguminous crops, leguminous crops had the highest biomass production compared to other crops. In an experiment conducted by Dabbaghi *et al.* (1394), no significant difference was observed in biomass production among green manure treatments, including the mixture of mung bean and clover, individual mung bean, and clover. The lowest dry weight was associated with oat green manure, which might be due to the high temperature during this cropping period and oat's intolerance to high temperatures. These findings are consistent with the results of this study. In studies by Ross *et al.* (2008), rapeseed produced more biomass compared to other legumes and oat. Torbert *et al.* (1996) reported higher biomass production in leguminous crops compared to non-leguminous crops.

The highest cover crop biomass in pure cultivation belonged to Sudan grass. In the second and third ranks were clover and mung bean. The lowest cover crop biomass was associated with pure cultivation of soybean and clover. Sudan grass, with its characteristic of being a C4 crop and having a strong ability to control weeds, occupied the first place. Furthermore, clover's ability to biologically inhibit nitrification through root exudates, particularly under drought stress conditions, can prevent nitrate leaching in the soil, contributing to an effective increase in wheat yield. The use of clover as a green manure cover crop in summer cultivation has demonstrated an improvement in wheat performance, which is a crucial point in transforming wheat agricultural systems towards water-saving practices.

Regarding the pearl millet cover crop, it's worth mentioning that according to the latest research in this field, pearl millet possesses the ability to biologically inhibit nitrification, especially through root exudates, particularly in drought stress conditions that might occur in the warm summer months. This inhibition prevents the leaching of stored nitrates in the soil, allowing the accumulated nitrogen to be utilized by wheat afterward (Ghatak *et al.*, 2022).

Table 4 - Two-Year Average Characteristics of Studied Green Manure Cover Crops in Experimental Treatments

		Two-year mean		
No.	**Green manure cover crop**	**Net Vegetation Biomass (grams per square meter)**	**Dry Biomass of Weeds and Vegetation Cover (grams per square meter)**	**Fresh Biomass (grams per square meter)**
1	**Grain sorghum**	718bc	874.2bcd	3280dce
2	**Forage millet**	965b	1077.2abc	4388bcd
3	**Sorghum-Sudan**	1395a	1506.3a	5748ab
4	**Barley**	299edf	591.3d	2169de
5	**Berseem clover**	673bd	923.5bcd	4481bc
6	**Crimson clover**	330edf	809.3bcd	3044dce
7	**Cowpea**	712bc	927.55bcd	3605bcde
8	**Canola**	626bcd	808.75bcd	3379dce
9	**Mung bean**	896bc	1132.55abc	4593bc
10	**Rye**	608bcde	699.85dc	1910e
11	**Hairy vetch**	596cdef	1178.3ab	6954a
12	**Oat**	532cdef	1022.5bcd	3545dce
13	**Safflower**	865bc	1084abc	4412bcd
14	**Soybean**	242ef	882.8bcd	3528dce
15	**Sesame**	317ef	931.2bcd	3483dce
16	**Sainfoin**	227f	931.3bcd	3992bcde

Table 3 demonstrates that the two-year mean characteristics of green manure cover crops varied across different experimental treatments. Percent dry matter, green manure biomass, weed biomass, dry weed biomass, and total biomass exhibited significant differences among various two-year treatments. The highest net biomass was attributed to Sorghum sudangrass, followed by crimson clover and mung bean. In contrast, the lowest net biomass was associated with berseem. Furthermore, other attributes such as percent dry matter and green manure biomass also exhibited significant variations among different two-year treatments. Based on these findings, the selection of suitable green manure cover crops for soil improvement, fertility enhancement, and weed suppression could have a considerable impact on agricultural system performance.

The traits related to wheat yield and its components were analyzed using the composite analysis of variance, as shown in Table 4. The results indicated that among the traits associated with wheat yield and its components, only the trait "number of spikes per square meter" did not exhibit a significant difference. Other traits, such as thousand kernel weight, harvest index, number of kernels per spike, kernel weight per square meter, grain yield, and biological yield, showed statistically significant differences. The percentage of variation in these traits also varied. The results demonstrated that the

factors of year, treatment, and the interaction between year and treatment significantly influenced wheat yield and its components.

Table 5 - Combined Analysis of variance for wheat traits

SOV	DF	Biological Yield	Grain Yield	Seed weight per sqm	Seeds per spike	Spike no.	HI	TGW
Year	1	5527200**	115047277.6**	5527200.3**	1268.76**	108608.7**	372.09**	0.57166ns
Rep (year)	4	97509.69ns	8646477.71**	ns97509.7	457.02**	1708.7ns	35.458ns	0.5188ns
GMCC	15	66512.17ns	938093.6ns	66512.2ns	35.54ns	20724.6*	21.660ns	0.23333ns
Year x GMCC	15	81210.3ns	1087285.5ns	81210.3ns	52.09ns	58.69ns	30.494ns	0.1400ns
Error		49576.8	673752.1	53973.3	39.42	10240.6	23.525	1.574
CV (%)		11.2	11.7	13.47	21.5	15.82	13.47	7.5

and: Significant at a level of 5 and 1 percent probability, respectively and *ns*: non-significant.

The biological yield of wheat increased in the second year compared to the first year, and the use of leguminous cover crops in the two agricultural years led to an increase in biological yield. The highest mean biological yield of wheat was attributed to the treatment with Lablab bean cover crop, while treatments with soybean and clover also showed good performance. (Table 5) The results indicate that leguminous cover crops have positive effects on wheat characteristics. Similar studies have also shown that the effect on wheat grain yield was not significant under the influence of cover crops, but there were significant differences in biological yield among different cover crops. The reason for the lack of difference in the effect on grain yield might be due to their limited impact on soil nutrients, short growth period, and low residue returned to the soil. Abedani *et al.* (2018) reported that the use of leguminous cover crops could lead to an increase in wheat biomass. Furthermore, Gerami *et al.* (2013) reported that the use of leguminous green manure, particularly lablab bean and mung bean, significantly increased the biological yield of wheat compared to the fallow treatment, attributing this increase to the enhanced effects of these leguminous cover crops on wheat grain yield. The application of legumes as green manure, through the addition of organic nitrogen to the soil, resulted in an increase in wheat biomass. (Nemeiksiene *et al.*, 2011)

The grain yield of wheat showed a significant difference between the two agricultural years, with an increase observed in the second year. The use of leguminous cover crops in consecutive agricultural years led to an increase in grain yield. The mean grain yield of wheat in the second year (8135 kg/ha) compared to the first year (6195 g/m²) indicated a 35% increase, equivalent to 1351 kg. Moreover, treatments following mung bean, sesame, and berseem cultivation exhibited higher grain yields. In terms of the characteristics of the number of spikes per square meter and the number of grains per spike, significant differences were observed between treatments in the two agricultural years. Treatments following buckwheat, oat, and soybean cultivation had the highest number of spikes, while treatments following sorghum Sudan grass and lablab bean had the lowest number of spikes. Additionally, the treatment following chickpea cultivation had the highest number of grains per spike, and cluster bean and mung bean also showed good performance. The use of leguminous cover crops, such as mung bean, resulted in an increase in the number of grains per spike and consequently an increase in wheat grain yield. Gerami *et al.* (2013) stated that among the green manure treatments, Lablab bean had the best effect on grain yield and biological yield. Modhej and Mohammadpour (2014) reported an increase in grain yield in green manure treatments (mung bean) compared to the fallow treatment due to an increase in the number of grains per unit area and biological performance. It seems that the simultaneous use of green and mineral fertilizers leads to increased absorption of

mineral nutrients and improved utilization of nutrients present in green manures by wheat. The results of Sharifi *et al.* (2018) indicated that the type of cover crop significantly affected grain yield, spike weight per square meter, and thousand-grain weight. Najafian *et al.* (2018) showed that the mean grain yield of 'Baharan' wheat variety in Karaj and Zarqan during the agricultural year 2008-2009 was 6352 kg/ha, compared to an mean yield of 6463 kg/ha for control varieties (Bahar and Pishtaz). The two-year mean yield of the 'Baharan' variety in this study, after cropping cover crops, was 8130 kg/ha, indicating a 27% improvement in yield compared to the mean yield of wheat in Alborz province. This suggests a 60% increase compared to the mean yield of wheat in Alborz province. (Najafian *et al.*, 2019)

Table6- Irrigated wheat grain yield means in different locations

Wheat grain yield after green manure cover crops in the 2nd Year of study (kg/ha)	Wheat grain yield of "Baharan" variety in Alborz province (kg/ha)	Overall irrigated wheat grain yield in Alborz province (kg/ha)
8130	6352	5067

Mohammadpour and colleagues (1401) demonstrated that cultivating mung bean as a green manure (non-protective cultivation) led to an increase in wheat grain yield compared to conventional conditions. The cultivation of mung bean on different dates as green manure has been an important ecological factor in increasing the organic matter and main nutrients content in the soil. Gerami *et al.* (1392) stated that among the green manure treatments, the mung bean had the best impact on grain yield and biological yield of faba bean. Belachew and Aberna (2011) reported that legume cultivation as green manure resulted in an increase in accessible nutrients and organic matter content in the soil, leading to an increase in wheat grain yield. The findings of Farzadi and Seyed Nooreddin (1392) indicated that mung bean cover crop not only controlled the dry weight of wheat weeds but also increased the number of grains per spike (148 spikes per square meter), the number of grains per spikelet (8 grains per spikelet), and consequently led to an increased yield of Chamran wheat variety (5.382 tons per hectare), by 1.341 kg per hectare compared to conventional cultivation (4.043 tons per hectare).

The TGW mean over the two-year study did not show a significant difference and ranged from 50 to 50.9 grams. The harvest index also did not exhibit a significant difference over the two-year and ranged from 39% to 43%. The number of spikes per square meter and the number of grains per spike also displayed a significant difference over the two-year study. According to the table7, treatments following the cultivation of hairy vetch, oat, and soybean had the highest wheat grain yield, while treatments following soybean and canola cultivation had the lowest wheat grain yield. Therefore, the use of green manure cover crops such as hairy vetch, oat, and soybean can potentially enhance wheat productivity for these traits (Table 6).

Table 7 - Two year means of wheat grain yield, biomass and grain yield components

No.	Green Manure Treatment	Biological Yield (kg/ha)	Grain Yield (kg/ha)	Seed Weight (g/m^2)	Number of Seeds per Spike	Number of Spikes per m^2	Harvest Index	Thousand Grain Weight (g)
1	Grain sorghum	17428 ab	6287.5 c	715.67ab	29.5ab	641abcd	40.8ab	52a
2	Forage millet	16835ab	7313.7 abc	709.83ab	28.8ab	657.5abcd	42.2ab	49.3ab
3	Sorghum-Sudan	17005 ab	7330.3 abc	724.67ab	27ab	551.2d	41.7ab	50ab
4	Barley	14348a	7069 abc	610.33b	28.2b	581.5bcd	42.3b	51.2ab
5	Berseem clover	16890 ab	6998.7 abc	689ab	26.3b	706.8a	40.5ab	51.5ab
6	Crimson clover	17805ab	7186.7 abc	752ab	28.8b	638.5abcd	41.7ab	51.2ab
7	Cowpea	18858 a	6863.8 bc	750.17ab	27.2ab	535.8d	39.8ab	49.2ab
8	Canola	18140 a	7204.3 abc	758.83ab	27.5ab	698abc	41.8ab	49ab
9	Mung bean	17550a	8105.2 a	712.83ab	32.2ab	691.8abc	40.5ab	52.5a
10	Rye	16578 a	7477.2 ab	700ab	35.3 a	653.7abcd	41.8ab	52.1a
11	Hairy vetch	16047 ab	7257 abc	715ab	32.7ab	616.8abcd	44.3ab	52.5a
12	Oat	17542 ab	7337.2 abc	768.5ab	29ab	711.8a	43.7ab	49.0ab
13	Safflower	16922ab	7535.2 abc	652.67ab	28.2ab	630.8abcd	38.2ab	49.5ab
14	Soybean	17890 a	7411.5 ab	753ab	28.8ab	723.2a	41.7ab	47.2b
15	Sesame	17708 a	7597 ab	677.5ab	30.3ab	563.7cd	37.7b	50.3ab
16	Sainfoin	18402 a	7654.3 ab	812.17a	26.7ab	629.3abcd	44.5a	51.3ab

Soil Organic Matter Properties

The soil organic matter properties did not show significant differences among different treatments of green manure cover crops. The soil test results before and after the use of green manure cover crops indicated that the mean percentage of soil organic carbon in the second agricultural year (2020-2021) was 0.81%, while it was 0.45% at the beginning of the study (2017-2018). These results suggest that within a short three-year period, soil organic carbon can be increased by annual rate of about 0.3%. Changes in soil organic carbon in the green manure cover crop treatments revealed that the highest amount of soil organic carbon was associated with the treatments of cowpea and mung bean, while the lowest amount was related to the treatments of soybean" and rye. The use of crops as green manure positively affects the increase in soil organic carbon and nitrogen content in the soil (Sabiene *et al.*, 2010), which is also confirmed by the results of the present study. Abdollahi and colleagues (1394) stated that after Sorghum forage, the highest amount of soil organic carbon belonged to candle or African clover with 1.12% for the year 1388 and 1.81% for the year 1389. Mandal *et al.* (2003) mentioned that green manure, particularly from "Mash," improves soil structure, increases the level of organic matter and nitrogen content in the soil, and enhances wheat grain yield.

Table 8 - Analysis of variance results for soil characteristics after green manure cover crops

SOV	DF	Mean Squares		
		Soil C/N	Total Nitrogen	Soil Organic Matter
Block	2	.1929	.01866	.0102
Treatment	15	.8782 ns	.017ns	.0121ns
Error	30	.1009	.1849	.1163
CV (%)	-	3.26	132	13.35

* and **: Significantly different at 1% and 5% probability levels, respectively.

In Table 8, the results of the analysis of variance for soil organic matter in different treatments of green manure cover crops are presented. The results showed that the total nitrogen content of the soil did not significantly differ among various treatments of green manure cover crops. The treatments of cowpea and mung bean exhibited the highest levels of total nitrogen in the soil, emphasizing that these crops have effectively grown and accumulated nitrogen in their biomass during the warm semi-summer period, making it available for subsequent wheat crops. On the other hand, the soybean treatment showed the lowest total nitrogen content, indicating that soybean as a green manure cover crop did not perform well in the latter half of summer and beyond.

Adding green manure crops to the soil is important for nitrogen and other nutrient release. The liberated nitrogen can be utilized by subsequent crops, reducing the risk of nitrogen leaching. The experimental results demonstrate that incorporating residues of leguminous crops (such as lentil, cowpea, chickpea, and various clover species) leads to an increase in the percentage of total nitrogen in the soil. The significance of incorporating green manure crops into the soil lies in the liberation of elements such as nitrogen from these crops. The released nitrogen from green manure crops can be utilized by subsequent crops, and as this nitrogen gradually becomes available from organic matter, the risk of leaching is reduced (Wade and Sanchez, 1983).

In a two-year experiment, Abdollahi *et al.* (1394) reported that the increase in the percentage of total nitrogen in the soil due to the incorporation of residues of leguminous crops, including lentil, cowpea, chickpea, and various clover species, was higher compared to other tested crops.

The results in Table 7 indicated that the soil carbon-to-nitrogen ratio (C/N) did not significantly differ among various treatments of green manure cover crops. The treatments of clustered mallow and sorghum Sudan grass exhibited the highest C/N ratios, while white clover and safflower had the lowest ratios. However, the C/N ratio alone cannot fully represent the soil's carbon and nitrogen status; attention should be given to the actual values of carbon and nitrogen as well as the C/N ratio of the soil. According to previous research, a high C/N ratio can lead to reduced mineralization and increased organic matter accumulation (Kumar and Goh, 2002).

Certain crops, such as white clover, berseem clover, crimson clover, mung bean, and cowpea, perform rapid decomposition due to their low C/N ratios. During this process, carbonic acid is released, leading to a decrease in soil acidity and an increase in the accessibility of phosphorus. Based on the results of a two-year experiment, white clover and mung bean, due to their low C/N ratios, enhance the availability of absorbable phosphorus and total nitrogen content in the soil for subsequent crops (Koocheki *et al.*, 2005). They are considered the most effective green manure among the studied crops.

Table 9 – Means of soil organic matter-related traits over two-year

No.	Green manure cover crop	Organic Matter (%)	C/N Ratio	Total Nitrogen (%)	Organic carbon content%
1	**Grain sorghum**	1.53a	9.9a	0.09a	0.89a
2	**Forage millet**	1.5a	9.7a	0.09a	0.87a
3	**Sorghum-Sudan**	1.45a	10a	0.083a	0.84a
4	**Barley**	1.34a	9.7a	0.08a	0.78a
5	**Berseem clover**	1.48a	9.5a	0.09a	0.86a
6	**Crimson clover**	1.56a	9.7a	0.093a	0.91a
7	**Cowpea**	1.29a	9.4a	0.1a	0.75a
8	**Canola**	1.26a	9.8a	0.073a	0.73a
9	**Mung bean**	1.58a	9.7a	0.095a	0.92a
10	**Rye**	1.29a	9.8a	0.077a	0.75a
11	**Hairy vetch**	1.31a	9.5a	0.08a	0.76a
12	**Oat**	1.29a	9.8a	0.077a	0.75a
13	**Safflower**	1.39a	9.7a	0.083a	0.81a
14	**Soybean**	1.45a	10a	0.083a	0.84a
15	**Sesame**	1.27a	9.7a	0.07a	0.74a
16	**Sainfoin**	1.32a	9.7a	0.08a	0.77a

Table 9 demonstrates that during the two-year of the study, the mean characteristics related to soil organic matter did not show a statistically significant difference among various treatments of green manure cover crops. The soil organic matter content ranged between 1.26% to 1.58%, carbon-to-nitrogen ratio ranged from 9.4 to 10, total nitrogen ranged from 0.07% to 0.1%, and organic carbon content varied between 0.73% to 0.92%. Additionally, all means have been denoted as equivalent with the letter "a," indicating that no significant statistical differences were observed among treatments for these characteristics.

Table 8 illustrates that following the use of green manure cover crops, there was an 80% increase in soil organic carbon content and an 80% increase in soil organic matter content. Furthermore, the carbon-to-nitrogen ratio (C/N) reduced from 11.25 to 9.60, indicating a decrease in the carbon-to-nitrogen ratio. However, the total soil nitrogen content experienced a significant 111% increase.

Table 8 demonstrates that the soil organic matter content increased from 0.78% to 1.4% over the two-year, indicating an 80% increase in soil organic matter. Furthermore, the soil organic carbon content

also increased from 0.45% to 0.8% over the two-year, representing an 80% increase in soil organic carbon. This increase could be one of the contributing factors to the improved wheat grain yield during the research period. Leguminous crops (nitrogen-fixing crops), such as chickling vetch, mung bean, and cluster bean, play a significant role in enhancing soil organic matter content. Additionally, treatments involving sorghum, Sudan grass, and foxtail mill*et al.*so exhibit substantial biomass production. These results emphasize that high biomass production alone cannot be the sole basis for selecting green manure, but attention must also be given to its effects on soil properties, particularly soil organic carbon.

Moreover, the findings indicate that the high temperatures in the month of August are not conducive to the optimal growth and development of chickling vetch and mung bean. As a result, these crops are not recommended as green manure cover crops during the mid to late summer period.

Table 10: Comparison of mean soil organic carbon percentage, total nitrogen percentage, soil organic matter, and carbon-to-nitrogen ratio before and after the application of green manure cover crops in the field.

Description	Soil Organic Carbon (%)	Soil Organic Matter (%)	Total Nitrogen (%)	Carbon-to-Nitrogen Ratio (C/N)
Before Cover Crop Treatment	0.45	0.78	0.04	11.25
After Cover Crop Treatment	0.81	1.4	0.0844	9.6
Percentage Increase	80%	80%	111%	14.69%

The research results indicate that green manure cover crops did not have a significant impact on wheat grain yield over the two agricultural years. However, the soil compound analysis showed that the experimental years of study had a considerable effect on wheat grain yield. In other words, cropping green manure cover crops before the main wheat crop, due to the stability of experimental units over two-year, had positive effects on wheat growth, yield, quality, and soil properties.

A significant increase of 81% in soil organic carbon percentage (from 0.45% initially to 0.81% in the final agricultural year) and improvements in physical, chemical, and biological soil properties, as well as the balance of microbial populations (such as bacteria and fungi), demonstrate that cropping green manure cover crops has a notable impact on soil health.

Based on the overall findings, green manure crops like mung bean, cluster bean, and chickling vetch are recommended for cultivation and incorporation into the soil during the latter half of summer until late Mehr month (end of September) – that is, before cropping wheat in each agricultural year.

Limitations and Future Research
The SOC and yield responses were observed over a relatively short two-year timeframe. Global meta-analyses show that SOC sequestration and soil function stabilization typically require 5–10 years or more of consistent management. Future studies should include long-term multi-site trials, soil carbon fractionation, greenhouse gas balance (CO2 and N2O), and economic performance to support scaling adoption.

Conclusion

As a result, this research has demonstrated that the use of green manure cover crops can have positive effects on the growth, yield, and quality of wheat, as well as improvements in soil properties. The significant increase in soil organic carbon percentage and the remarkable enhancement of physical, chemical, and biological soil attributes indicate improved soil health. Based on these findings, it is recommended that green manure crops such as mung bean, cluster bean, and chickling vetch be cropped and incorporated into the soil at the appropriate time (mid-summer to late September) to induce the observed enhancements in soil characteristics and wheat performance. Overall, utilizing green manure cover crops as a sustainable strategy can have a significant impact on enhancing soil health and agricultural productivity improvements.

The research findings indicate that green manure cover crops did not have a significant effect on wheat grain yield over the two agricultural years. However, based on the results of the soil composite samples analysis the experimental years of study had a significant effect on wheat grain yield. In other words, cropping green manure cover crops before the main crop wheat, due to the stability of the experimental units over the years of study, had positive effects on wheat growth, grain yield, grain quality. Increase in soil organic carbon content by 35% (from 0.6% at 1st year to 0.81% in 2nd year) and improvements in soil chemical, physical and biological characteristics demonstrate the significant influence of cropping green manure cover crops on soil health. In relation to dry biomass production, Sudan grass, cowpea, mung bean, and forage sorghum are suggested. Considering the influence of green manure cover crops on wheat grain yield and yield components, mung bean, green bean, and fenugreek are also recommended. Moreover, prioritizing the enhancement of soil organic matter, mung bean, green bean, and cluster bean take the lead, followed by sorghum, clover, and Sudan grass for subsoil incorporation during the late summer through late Mehr (September-October) before wheat cropping in each agricultural year.

Acknowledgement

Deep appreciation to the Cereals Research Department in Seed and Plant Improvement Institute: Acknowledging the Indispensable Contribution of Academic Staff, Researchers, and Experts in Enabling the Progress of this Research.

References

1. Abdani, F., Farzaneh; M., Maskarbashy, M. (2018). The effect of cover crops of chickpea and buckwheat and their residues on weed infestation, Wheat yield, and yield components. Plant ecophysiology, 10(35), 221-233. SID.
2. Abdi, Sakineh; Tajbakhsh, Mehdi; Abdollahi Mandolakani, Babak; and Rasouli Sedghiani, Mirhossein. (2015). The Effect of Different Green Manure Plant Residues on Available Phosphorus, Nitrogen Content, and Soil Organic Carbon. Applied Agricultural Research (Research and Development), 28(107), 48-57. SID.
3. Adetunji.Adewole, Tomiwa , B. Ncube , R.Mulidzi, Francis Bayo Lewu. 2020. Management impact and benefit of cover crops on soil quality: A review: A review, , , October 2020, 104717.
4. Ataure Rahman, M., Chikushi, J., Saifizzaman, M., and Lauren, J.G. 2005. Rice straw mulching and nitrogen of no-till wheat following rice in Bangladesh. Field Crops Research, 91: 71-81.

5. Belachew, T. and Abera, Y. 2011. Effect of green manuring in combination with nitrogen on soil fertility and yield of bread wheat (Triticum aestivum L.) under double cropping system of Sinanadinsho, Southeast Ethiopia Journal of Biodiversity and Environmental Sciences1 (1): 1-11.
6. Chahal, I., & Van Eerd, L. L. (2023). *Do cover crops increase subsequent crop yield in temperate climates? A meta-analysis*. Sustainability, 15(8), Article 6517. https://doi.org/10.3390/su15086517 MDPIGoogle Scholar.
7. Creamer, N.G. and K.R. Baldwin. 2000. An evaluation of summer cover crops for use in vegetable production systems in North Carolina. HortSci. 35(4):600-60McDaniel M, Tiemann L and Grandy AS, 2014. Does agricultural crop diversity enhance soil microbial biomass and organic matter dynamics? A meta-analysis. Ecological Applications, 24: 560–570.
8. Dabighi, Khatoun; Fateh, Esfandiar; Ayenehband, Amir. (2016). The Effect of Green Manure Plants on Soil Fertility and Reduction of Weed Density. Plant Productions (Journal of Agricultural Sciences), 39(2), 1-10. SID.
9. Delgado, J.A., R.R. Riggenbach, R.T. Sparks, M.A. Dillon, L.M. Kawanabe, and R.J. Ristau. 2001b. Evaluation of nitrate nitrogen transport in a potato-barley rotation. Soil Science Society of America J. 65:878-883.
10. Didon, U.M.E., Kolseth, A.K., Widmark, D. & Persson, P. (2014). Cover crop residues-effects on germination and early growth of annual weeds. Weed Science, 62, 294-302.
11. Ding, W., [Co-authors]. (2025). *Insights from a 20-year field experiment and meta-analysis: Conservation tillage increases carbon stock*. Agriculture, Ecosystems & Environment, 393, Article 109845. https://doi.org/10.1016/j.agee.2025.109845 ScienceDirect+1.
12. Fan, F., van der Werf, W., Makowski, D., Ram Lamichhane, J., Huang, W., Li, C., Zhang, C., Cong, W.-F., & Zhang, F. (2021). Cover crops promote primary crop yield in China: A meta-regression of factors affecting yield gain. *Field Crops Research*, 271, 108237. https://doi.org/10.1016/j.fcr.2021.108237
13. FAOsat. 2022. World Food and Agriculture – Statistical Yearbook 2022. Rome. .
14. Farzadi, Hossein; and Seyyed Masoum, Seyyed Nooreddin. (2013). The Effect of Cover Crops on Weed Dry Weight and Chamran Wheat Yield in Northern Khuzestan. Seed and Plant Journal (Seed and Plant), 29-2(4), 569-581. SID.
15. Francaviglia, R.; Almagro, M.; Vicente-Vicente, J.L.2023 Conservation Agriculture and Soil Organic Carbon: Principles, Processes, Practices and Policy Options. Soil Syst. 2023, 7, 17. https://doi.org/10.3390/ soilsystems7010017
16. Gentsch, N., [Co-authors]. (2024). *Cover crops improve soil structure and change organic carbon fractions in arable soils*. SOIL, 10, 139–156. https://doi.org/10.5194/soil-10-139-2024 soil.copernicus.org.
17. Gerami, Farzad; Ayenehband, Amir; and Fateh, Esfandiar. (2013). The Effect of Green and Chemical Nitrogen Fertilizers on Germination, Yield, and Yield Components of Wheat (Triticum aestivum L). Agricultural Science and Sustainable Production (Agricultural Sciences), 23(1), 0-0. SID.
18. Ghafari, M., Elahi panah, F., Soghani, M., Nadali, A. and Morovati, A. 2011. Ecological control of weed by cover crops: effect on winter weed and weed stabilized in potato culture. Proc. the National Conf. of New Achievements in Agronomy. Islamic Azad University of Shahre-Qods, Iran. (In Farsi).
19. Ghatak, A., Schindler, F., Bachmann, G., Engelmeier, D., Bajaj, P., Brenner, M., Fragner, L., Varshney, R. K., Subbarao, G. V., Chaturvedi, P., & Weckwerth, W. (2022). Root exudation of contrasting drought-stressed pearl millet genotypes conveys varying biological nitrification inhibition (BNI) activity. *Biology and Fertility of Soils*, 58(3), 291–306. https://doi.org/10.1007/s00374-021-01578-w.
20. Guo, R., X. Li, P. Christie, Q. Chen, R. Jiangand F. Zhang., 2008. Influence of root zone nitrogen management and a summer catch crop on cucumber yield and soil mineral nitrogen dynamics in intensive production systems. Plant Soil,313:55–70.
21. Hasheminasab, F. S., M. Mousavi Baygi, B. Bakhtiari and M. Bannayan Aval. 2014. The effects of rainfall on dryland wheat yield and water requirement satisfaction index at different time scales. Iran. Soc. Irrig. Water. 5(17): 1-13.
22. Heydarzadeh, Saeed & Jalilian, Jalal. (2019). The Impact of Different Fertilizers and Cover Crops on Weed Control and Some Quality Traits of Safflower (Carthamus tinctorius). Arjmand, Ali; Fateh, Farid; Esfandiar, Esfandiar; and Ayenehband, Amir. (2014). The Effect of Different Green Manure Incorporation Times on Soil Nutrient Content. Proceedings of the Iranian Congress of Crop Science and Plant Breeding. SID.
23. Hooker KV, Coxon CE, Hackett R, Kirwan LE, Okeeffe E and Richards KG, 2008. Evaluation ofcover crop and reduced cultivation for reducing nitrate leaching in Ireland. Journal of Environmental Quality, 37: 138-145
24. Jian Jinshi a b, Xuan Du c, Mark S. Reiter a d, Ryan D. Stewart a,2020 A meta-analysis of global cropland soil carbon changes due to cover cropping, - Soil Biology and Biochemistry, , April 2020, 107735

25. Joshi, D. R., Clay, D. E., & [other authors as available]. (2023). *A global meta-analysis of cover crop impacts on soil organic carbon*. Agronomy Journal, 115(6), 1543–1555. https://doi.org/10.1002/agj2.21340 acsess.onlinelibrary.wiley.comPhys.org.
26. Koocheki, A., Gholami, A., Mahdavi Damghani, A. and Tabrizi, L. (2005). Organic field crop. Ferdowsi University of Mashhad Publisher. 385pp. (Translated in Persian(
27. Kuma,r K. and Goh, K.M. (2002). Management practices of antecedent leguminous and non–leguminous crop residues in relation to winter wheat yields, nitrogen uptake, soil nitrogen mineralization and simple nitrogen balance. European Journal of Agronomy. 16: 295–308
28. Mandal, U.K., Singh, G., Victor, U.S.,and Sharma, K.L. 2003. Green manuring: its effect on soil properties and crop growth under rice/wheat cropping system. Europ Journal
29. Mazzoncini, M., Sapkota, T. B., Barberi, P., Antichi, D. & Risaliti, R.(2011) Long-term effect of tillage, nitrogen fertilization and cover crops on soil organic carbon and total nitrogen content. Soil Till. Res. 114, 165–174 (2011).
30. Mehrvar, Mohammad Reza. (2022). Agronomic and economic assessment of cover crop effects on irrigated wheat productivity and quality under double minimum tillage and raised bed cropping systems, Final report of approved project number: 960503-055-03-03-2. Agricultural Research, Education and Extension Organization - Seed and Plant Improvement Institute - Karaj, Iran. 2022-2023.
31. Modhej Adel and Mohammadpour Abdulrahim. (2013). The Effect of Green Manure and Different Levels of Phosphorus and Nitrogen Fertilizers on Wheat Yield under Dezful Environmental Conditions. Crop Plant Physiology Scientific Journal - Islamic Azad University, Ahvaz Branch, Fifth Year, Nineteenth Issue, Autumn 2013.
32. Mohammadpour, Abdulrahim; Hanounian, Saroon; Modhej, Adel. (2022). Investigating the Possibility of Increasing the Efficiency of Different Levels of Nitrogen and Phosphorus Fertilizers by Altering the Planting Date of Green Manure Mung Bean in Autumn Wheat Cultivation. Journal of Soil Management and Sustainable Production, 12(3), 113-131. DOI:
33. Najafian, Gholamreza; Khodarahmi, Mehdi; Bakhtiyar, Farhad; Nikoseresht, Reza; Nikzad, Alireza; Ahmadi, Gholam Hossein; Afioni, Davood; Ja'farnajad, Asghar; Hassampour, Javad; Afshari, Farzaneh; Atahosseini, Mehdi; Zakeri, Amir; Mehrabi, Reza; Dehnavi, Babak; Nazari, Alireza; Badri, Ali; Kia, Shahram; Tabatabaei, Nasrin. (2017). Baharan: A New Spring Bread Wheat Variety Tolerant to Late-Season Drought and with Good Baking Quality for Cultivation in Irrigated Areas of Moderate Regions of Iran. Scientific and Promotional Quarterly of Research Findings in Field and Horticultural Plants. 6(1): (11-21).
34. Najafian, Ghoodarz; Khodarahmi, Manoochehr; Bakhtiyar, Farshad; Nikoseresht, Reza; Nikzad, Alireza; Ahmadi, Gholam Hossein; Afiooni, Davood; Jafarnajad, Asghar; Hessampour, Javad; Afshari, Farzad; Atahosseini, Mehdi; Zakeri, Amir; Mehrabi, Reza; Dehnavi, Babak; Kabirian, Hamid Reza; Nazari, Ali; Badri, Ali Reza; Kia, Shahram; Tabatabaei, Nasrin. (2017). Baharan: A New Spring Bread Wheat Variety Tolerant to Late-Season Drought and with Good Baking Quality for Cultivation in Irrigated Areas of Moderate Regions of Iran. Scientific-Extension Journal of Research Findings in Field and Horticultural crops. 1-11: (1) 6.
35. Nemeikšienė, D., Arlauskienė, A. and Šlepetienė, A. 2011. Improvement winter wheat yields in organic farming systems through innovation in green manure management. Environment. Technology. Resources Proceedings of the 8th International Scientific and Practical Conference.11: 268- 275
36. Oldfield. E, Mark A. Bradford, and Stephen, A. Wood. 2019. Global meta-analysis of the relationship between soil organic matter and crop yields, SOIL geoscience union., .SOIL, 5, 15–32, 2019https://doi.org/10.5194/soil-5-15-2019
37. Poffenbarger, H., S.Mirsky, R.Weil, J.Maul, M.Kramer, J.Spargo, M.Cavigelli., 2015. Biomass and nitrogen content of hairy vetch-cereal rye cover crop mixtures as influenced by species proportions.Agron.J.,107:2069–208
38. Qiu, T.**,** Shi, Y., & Fang, L. (2024). *Optimizing cover crop practices as a sustainable solution for global agroecosystems*. Nature Communications, 15, Article 54536. https://doi.org/10.1038/s41467-024-54536-z Nature.
39. Rahimizadeh, M., Kashani, A., and Zarea Fizabadi, A. 2010. Effect of pre-sowing crops and returning crop residue nitrogen on growth and yield of wheat. Iranian Journal of Field Crops Research 8(1): 98-110
40. Reddy, K. H. and H. F. Hodges. 2000. Climate Change and Global Crop Productivity. UK, Wallingford. Vaiciulyte Funki, L., G. Juodeikiene and E. Bartkiene. 2015. The relationship between wheat baking
41. Reuters. (2024, April 11). U.S. bets on climate-friendly farming; experts doubt it is climate-friendly enough. Reuters.

42. Rosa HA, Secco D, Veloso G, Santos RF, Souza SNM, Marins AC and Borosi A, 2012.Effects of the use of cover crops in the structure of an oxisol managed by a no-till farming system in the west of Paraná, Brazilian Journal of Food, Agriculture and Environment, 10: 1278-1280.
43. Ross, S.M., King, J.R., Izaurralde, R.C., and O'Donovan, T. 2008. The green manure value of seven clover species grown as annual crops on low and high fertility temperate soils. Canadian Journal of Plant Science, 89: 465-476
44. Saadat, D., Hashemi, M., Herbert, S., & Siller, A. (2025). *Contribution of roots and shoots of three summer cover crops to soil C and N cycling post-termination*. Agronomy, 15(6), Article 1467. https://doi.org/10.3390/agronomy15061467 MDPI.
45. Sabiene, N., Kusliene, G. and Zaleckas, E. (2010). The influence of land use on soil organic carbon and nitrogen content and redox potential. Agriculture. 97(3): 15-24.
46. Sadeghpour, A., Hashemi, M., DaCosta, M., Jahanzad, E. and Herbert, Switchgrass establishment influenced by S.J. 2014. cover crop, tillage systems and weed control. BioEnergy Research 7 (4), 14021410-
47. Schlegel, A. J. and J. L., Javlin, J. L. 1997. Green fallow for the central great plains. Agronomy Journal. 89: 762-767.
48. Sen Li, Danmei Gao, Xiao Guo, Xingang Zhou and Fengzhi Wu .2017. Effects of Different Summer Cover Crops and Residue Management on Plant Growth and Soil Microbial Community.
49. Sharifi, Zahra; Eslami, Seyed Vahid; Jami Al-Ahmedi, Majid; and Mahmoudi, Sohrab. (2018). The Impact of Different Tillage Methods and Cover Crops on Wheat Yield and Yield Components. Iranian Journal of Crop Research, 16(1), 217-228. [Link].
50. Torbert, H.A., Reeves, D.W., and Mulvaney, R.L. 1996. Winter legume cover crop benefits to corn: rotation vs. fixed nitrogen effects. Agronomy Journal, 88: 527-535
51. Uchino, H., Iwama, K., Jitsuyama, Y., Yudate, T. and Nakamura, S. 2009. Yield losses of soybean and maize by competition with inter-seeded cover crops and weeds in organic – based cropping systems. Field Crops Res. 113: 342-351.
52. Wade, M.K. and Sanchez, P.A. (1983). Mulching and green manure applications for continuous crop production in the Amazon Basin. Agronomy Journal. 75: 39-45.
53. Weston, L.A., R. Harmon, and S. Mueller. 1989. Allelopathic potential of sorghum sudangrass hybrid (Sudex). J. Chem. Ecol. 15(6):1855-1865.
54. Wittwer, R. A., Dorn, B., Jossi, W., and van der Heijden, M. G. A. 2017. Cover crops support ecological intensification of arable cropping systems. Sci. Rep. 7:41911. Doi: 10.1038/srep41911
55. Wu, Y., X. Zhang, L. Gao, L. Yuan and, W. Wei, 2006. Effect of different cultivation patterns on continuous cropping soil environment and cucumber growth. In: XXVII International Horticultural Congress IHC2006, International Symposium on Advances in Environmental Control, Automation761:547–554R Development Core Team, 2010. R, a Language and Environment for Statistic Computing. R Foundation for Statistical Computing, Vienna, Austria, URL http://www.R-project.org.